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CHARACTERIZATION OF WESTERN CANADIAN COALS WITH RESPECT TO THEIR SUSCEPTIBILITY TO SPONTANEOUS COMBUSTION

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CHARACTERIZATION OF WESTERN CANADIAN COALS WITH RESPECT TO THEIR
SUSCEPTIBILITY TO SPONTANEOUS COMBUSTION

by

R.N. Chakravorty* and K. Kar**

ABSTRACT

Characterization of Canadian coals with respect to their susceptibility to spontaneous combustion is considered essential for safe mining, storage and transportation of coal.

This report briefly discusses the commonly used methods based on thermal changes for determining relative susceptibility of coals to spontaneous combustion and also presents the test results for a number of Western Canadian coals based on crossing point temperature and oxygen absorption test methods.

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CARACTÉRISATION DES CHARBONS DE L'OUEST CANADIEN PAR RAPPORT
À LEUR SUSCEPTIBILITÉ À LA COMBUSTION SPONTANÉE

par

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RÉSUMÉ

Il est nécessaire de caractériser les charbons canadiens par rapport à leur susceptibilité à la combustion spontanée afin de pouvoir effectuer de façon sécuritaire l'exploitation, le stockage et le transport du charbon.

Le présent rapport traite brièvement des méthodes utilisées généralement, et qui sont basées sur les changements thermiques, afin de déterminer la susceptibilité relative des charbons à la combustion spontanée. Il présente, de plus, les résultats d'essais obtenus pour de nombreux charbons de l'Ouest canadien à partir de la température du point de croisement et des méthodes d'essais d'absorption d'oxygène.

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INTRODUCTION

The problem of spontaneous combustion is as old as coal mining. There is no simple method by which one can assess whether mining or storage of coal will result in liability to spontaneous combustion. It is well known that coal can oxidize at ambient temperature producing heat. The hazard arises where the amount of heat evolved is more than the heat dissipated to the surroundings causing a rise of temperature that ultimately results in a fire caused by spontaneous combustion. However, a knowledge of relative susceptibility of coals to spontaneous combustion is very useful in starting to mine a new seam, in helping to make decisions on the precautions needed in selecting mining methods and to determine if one part of a seam is likely to prove more hazardous than others.

FACTORS INFLUENCING SPONTANEOUS COMBUSTION

It has been observed that the spontaneous combustion susceptibility differs with the nature of coal and attempts have been made to identify why these differences exist. Some constituents of coal particularly vitrain is considered to be most susceptible to spontaneous combustion. Chamberlain recently indicated that exinite has a greater oxidation rate particularly over 75°C compared to that vitrinite and inertinite from the same coal [1]. Certain forms of pyrite in particular the amorphous variety if present in the coal help in the oxidation process. Self heating of coal is directly related to exposed surface area. Thus friable coals which produce a considerable amount of fines when mined are usually more vulnerable. Coals of low thermal conductivity are more prone to spontaneous combustion due to the slower rate of heat dissipation. Moisture plays a very significant role in the low temperature oxidation of coal. High moisture coals are, in general, more liable to spontaneous combustion. Humid air also aids spontaneous heating. The heat released by dry oxidation at ordinary temperature is negligible compared to the heat released when the air is moist. Absorption of water by coal accelerates and desorption retards the process. Heat of wetting is often sufficient to raise the coal temperature to dangerous levels. Wetting of partly dried coal of high inherent moisture often results in spontaneous heating.

The occurrence of spontaneous combustion depends both on the intrinsic factors related to coal properties as discussed and also on extrinsic conditions such as mining and storage practices. Over the years it has been observed that in most cases the mining and storage practices become the overriding factor. Under favourable heat accumulation conditions, spontaneous combustion can occur with any type of coal and there have been numerous instances of this occurring to coals of low moisture, low pyrite and volatile matter which are usually considered to be relatively safe. Mining and storage methods which significantly influence onset of spontaneous combustion has been discussed in detail in an earlier publication [2].

REVIEW OF TEST METHODS

Evaluation of laboratory methods developed to date show that it is virtually impossible to simulate all the conditions existing in an operating mine and researchers have had to settle for tests which are empirical in nature. For characterization of coals with respect to their susceptibility to spontaneous combustion, experiments have been designed where the lowest temperature at which exothermic reaction becomes self propellent could be experimentally determined. To date numerous laboratory methods have been developed based on this approach in different parts of the world. The more common being:

- (i) Determination of Initial Temperature
- (ii) Differential Thermal Analysis
- (iii) Determination of Crossing Point Temperature.

Though none of these methods are universally acceptable, all the three tests could relate to spontaneous heating characteristics of coal fairly effectively as they simulate conditions more closer to conditions existing in a mining environment compared to other methods which are based solely on the chemical and physical properties of coal.

A brief description of these methods is summarized below.

Initial Temperature

Coal samples, being subjected to a current of air in a constant temperature oven set at a particular initial temperature, would show a progressive increase in temperature and if continued for an indefinite period may result in a fire caused by spontaneous combustion. For each coal a number of experiments are performed at different initial temperatures to determine the lowest temperature above which accelerated increase in temperature due to spontaneous combustion cannot be prevented. This temperature, called the initial temperature, is considered to be unique for the coal tested [3]. It is believed that coals with higher susceptibility to spontaneous combustion will have low initial temperature and with low susceptibility will have high initial temperature. The experiments, in general, are time consuming and so far little used for coal categorization.

Differential Thermal Analysis (DTA)

This technique involves heating a small specimen at a constant rate and continuously recording the temperature difference between it and an identically heated inert reference material as a function of temperature prevailing in the inert medium. The resultant thermogram (T against ΔT) depicts the physical and chemical changes of the material at a particular temperature and is a characteristics of the material used. Banerjee and Chakravorty [4] used this technique for comparing the spontaneous heating susceptibility of different coals. They recognized three stages of transition in the DTA thermograms in samples heated up to 300°C. During the initial stage of heating it is the endothermic reaction that predominates mainly from the release of moisture from coal. This is followed by exothermic reaction which takes into account a number of concurrent reactions and ultimately in the third phase leads to a reaction of high exothermicity. The rate of rise in heat evolution in phase two was observed to be much lower for coals with lower susceptibility to spontaneous heating thereby delaying the initiation of phase three. The exothermicity in the third phase was found to be high for most of the coals tested. Categorization based on DTA method is possible by taking into consideration only phase two of DTA thermogram. A typical thermogram is shown in Figure 1. The interpretation of results from the thermogram is often subjective

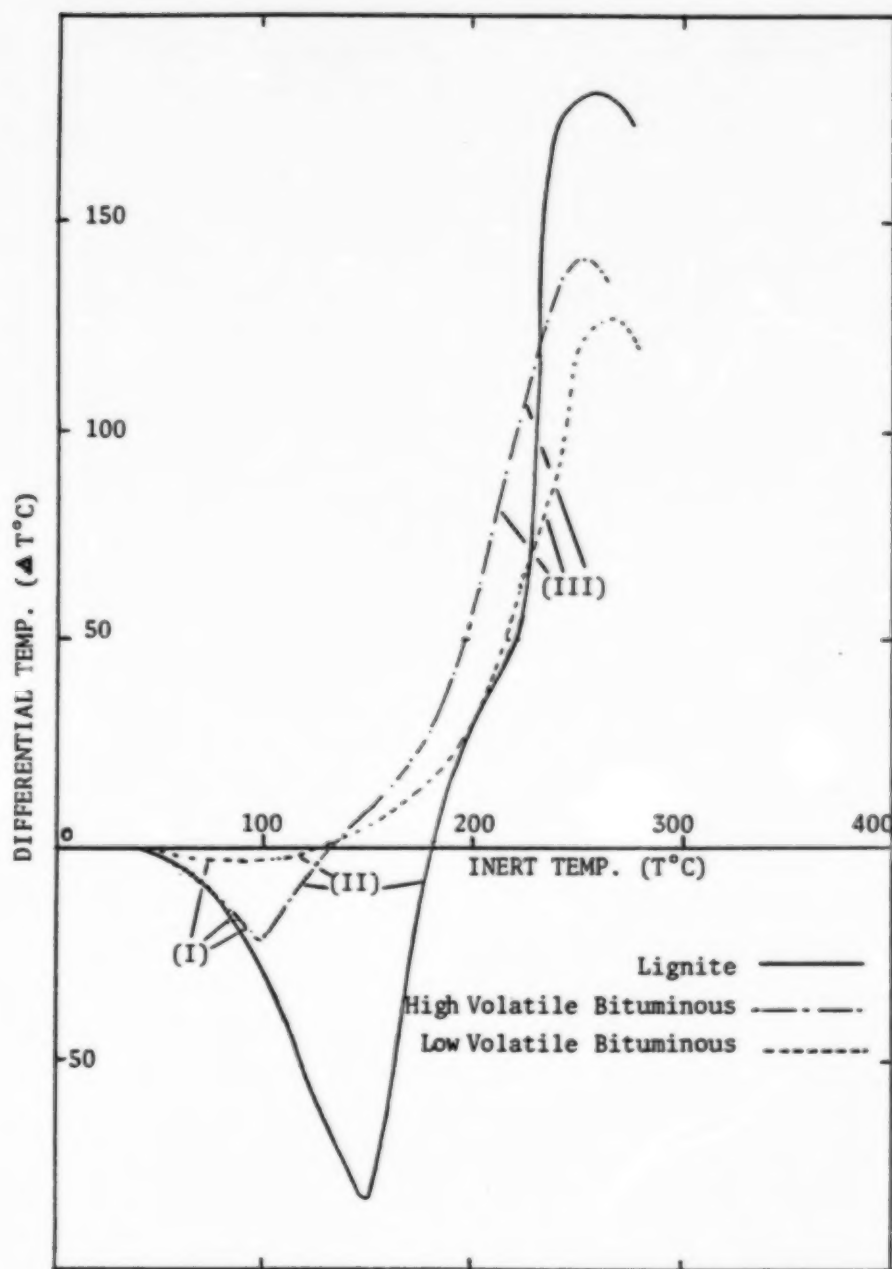


Figure 1 - Thermograms for low and high volatile bituminous coals.

and this may introduce errors. French scientists who have also used this technique considers that interpretation based on the rate of rise in temperature in the DTA thermogram may prove more useful for determining spontaneous combustion characteristics of coals [4].

Crossing Point Temperature

This method envisages heating coal samples in an oxidizing atmosphere at a definitely programmed rate of temperature rise. Due to exothermicity of oxidation reaction, at some point the coal bed temperature exceeds the bath temperature which is commonly termed as crossing point temperature. Coals highly susceptible to spontaneous heating would have lower values and coals with lower susceptibility will have comparatively higher values. Various experimental techniques and designs of apparatus have been used for the determination of crossing point temperature. It has been observed that the values of crossing point temperature for a coal sample depends to a certain extent on the design of the apparatus and also on the experimental parameters. Because of its simplicity this method is gaining increasing acceptance in different countries. A crossing point index has the advantage that it is easily determined not unduly subjected to experimental errors, the variables are easily controlled and the result undoubtedly represents a danger point in the progress of oxidation.

Oxygen Absorption Method:

This was the earliest attempt to develop a laboratory method suitable for determining spontaneous combustion liability of coals and has been used successfully ever since [1]. Freshly ground coal is put into a container maintained at a fixed temperature and the head gas is analysed periodically for the depletion of oxygen up to a period of 96 hours. A number of British coals were tested using this method and it was found that coals which are not highly susceptible to spontaneous combustion absorbed less than 200ml of oxygen/100gm of coal during 96 hrs at 30°C while for coals which are highly prone to spontaneous combustion, the amount of oxygen absorbed was more than 300ml during the same period. This method has been modified from time to time to carry out tests at an elevated temperature of 40°C to 60°C and attempts have been made to interpret test results based not

only on absorption of oxygen but also on products gases generated during low temperature oxidation.

It is interesting to note that this method is still considered practical and useful in determining relative susceptibility of coals to spontaneous combustion in many countries.

EXPERIMENTAL

Based on this review experimental facilities were set up for carrying out the following two tests:

- (i) Crossing point temperature determination.
- (ii) Oxygen absorption at isothermal conditions.

Crossing Point Temperature Test

At the Coal Research laboratory, Canada Centre for Mineral and Energy Technology, (CANMET), the crossing point temperature determination referred to earlier is carried out using the experimental set up as shown in Figure 2. An oven where the temperature could be programmed and increased at a predetermined rate was used for this study (Figure 3). Coal sample holders and stainless steel containers used for this test are shown in Figure 4. Two sets of thermocouples were attached to this set up, one for monitoring the coal bed temperature and the other for monitoring temperature of the oven as shown in Figure 2. Progressive temperature rise in the coal bed is monitored and recorded as the temperature of the oven is increased in a predetermined manner.

Coal sample preparation is done following a procedure where atmospheric oxidation is reduced to a minimum. Fresh coal immediately after sampling at the mine site is kept in a container. An inert atmosphere is maintained inside the container by replacing the air of the container with argon. The coal samples are crushed in a pulverizer or a ball mill maintaining an inert atmosphere. The samples are sieved to $-60 + 200$ mesh size. All the coals tested were equilibrated at 60% R.H. over a 48 hour period in an inert atmosphere to simulate normal atmospheric conditions.

Air is passed through the coal bed after presaturation with water vapour at a rate of 80ml/min. The temperature of the oven is increased at a rate of $0.5^{\circ}\text{C}/\text{min}$. Temperature of the oven and the coal bed is monitored

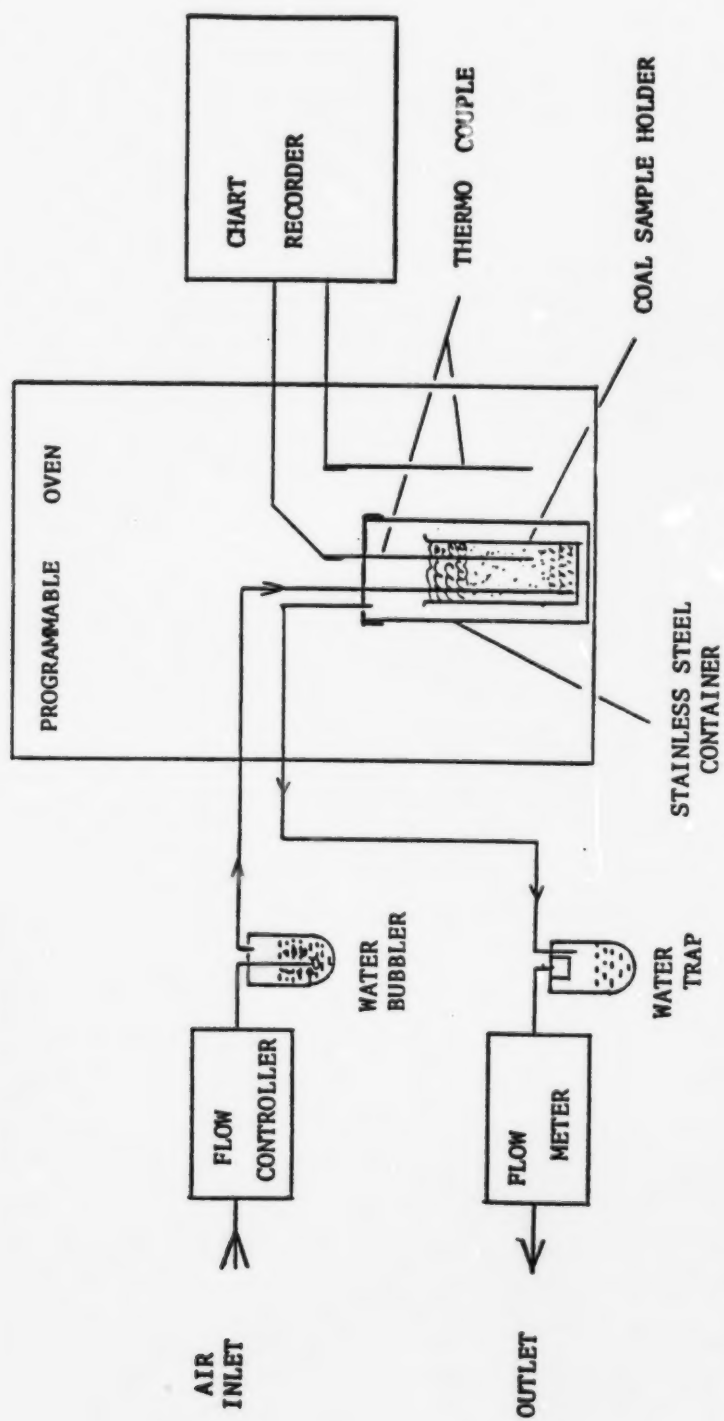


Fig. 2 - Experimental setup for determining crossing point temperature.

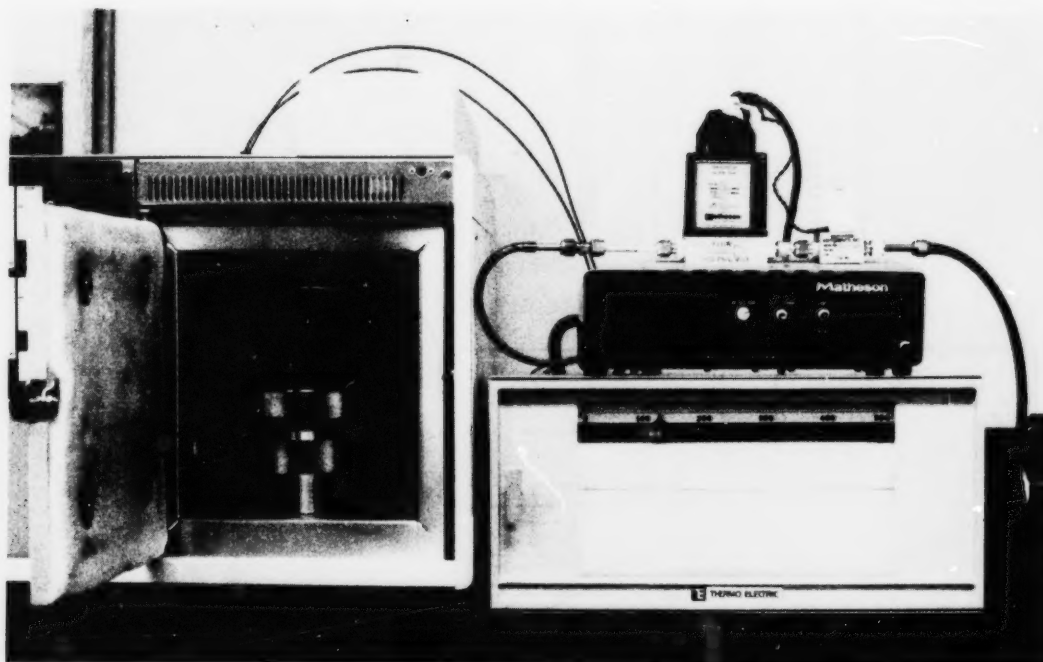


Figure 3. Crossing point temperature determination apparatus

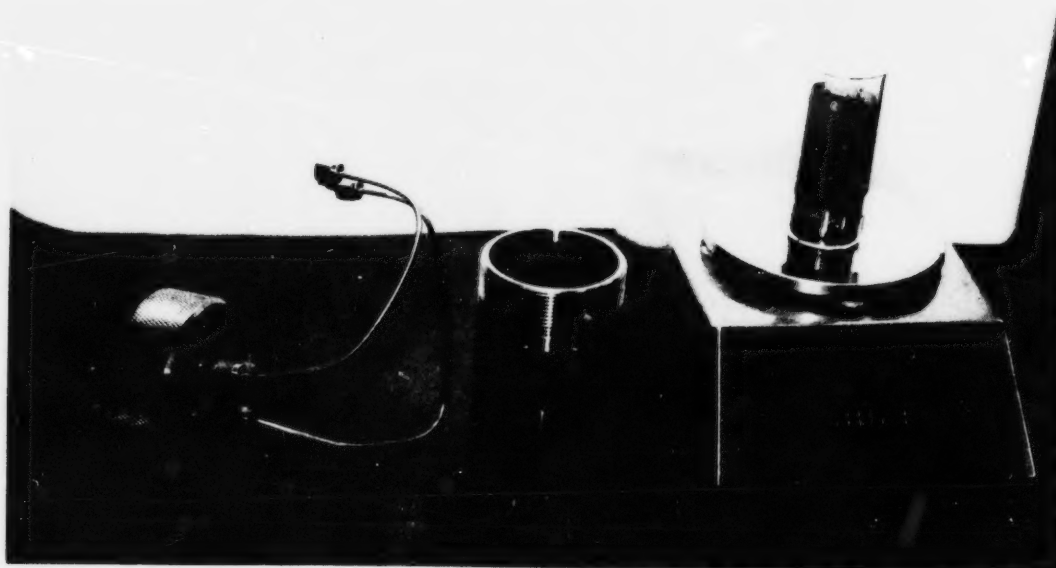


Figure 4. Coal sample container for crossing point temperature apparatus

on a continuous basis during the experiment. Amount of coal sample used for each test is 50gm.

Oxygen Absorption Test

Oxygen absorption experiments were carried out by placing 100gm of coal sample in an enclosed container about 2 litres in volume and noting the drop in pressure with time. The head gas was analysed after 96 hours for percent of oxygen and carbon monoxide using a gas chromatograph. Pressure drop in the container was also recorded at intervals during this period so that the pattern of oxygen absorption for different samples of coal could be observed. Apparatus for oxygen absorption test is shown in Figure 5. The head gas analysis system using gas chromatograph is shown in Figure 6.

DISCUSSION

A number of coals from different regions of Western Canada were analyzed and tested for spontaneous combustion characteristics. The coals were so chosen that all ranks of coal produced in Western Canada could be represented during the first phase of this study. Low volatile metallurgical coals were collected from Smoky River and Cardinal River operations. From the plains and foothills of Alberta, coals were collected from three different operations e.g. Luscar, Highvale, and Obed Marsh. Lignite samples were obtained from Saskatchewan Coal operations. The samples included two low volatile bituminous coals, six high volatile bituminous/subbituminous coals and one lignite. To maintain confidentiality, the coal samples are identified as A-J without indicating the name of coal producers.

Results of the crossing point tests are shown in Table 1 and Figures 7 to 9. The proximate and ultimate analyses of the coal samples tested are also given in Tables 2 and 3. Exinite content of the samples tested is given in Table 3.

The results obtained so far indicate that the crossing point temperature method is suitable for categorizing Western Canadian coals with respect to their susceptibility to spontaneous combustion. Attempts were made to correlate crossing point temperatures with the rank of coal. Carbon content of coal was plotted against crossing point temperatures as shown in Figure 10. The graph indicates that, in general, the crossing point

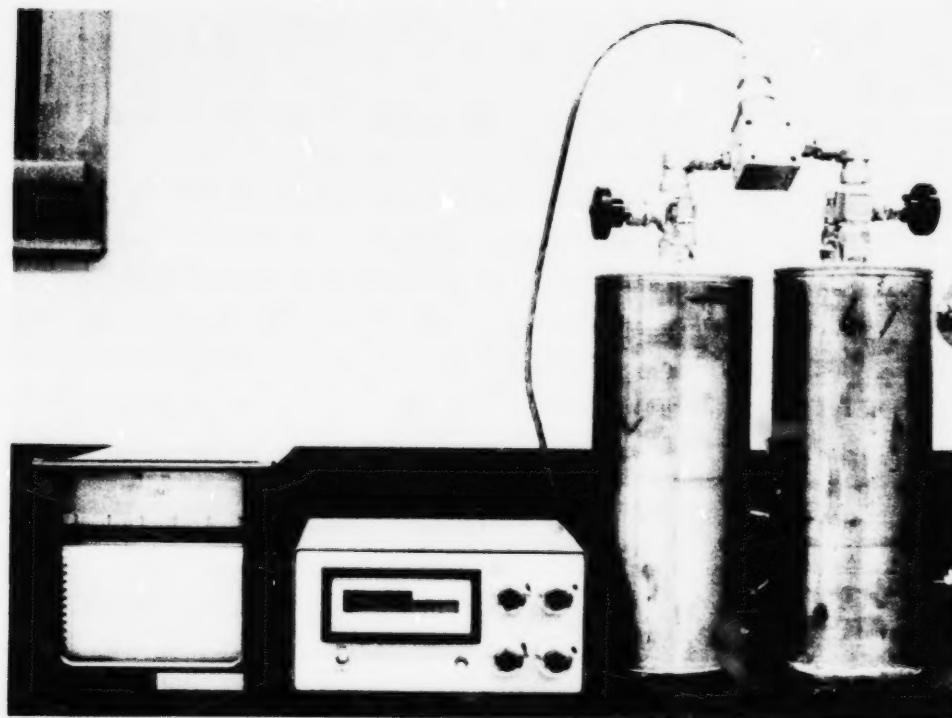


Figure 5. Laboratory set up for oxygen absorption tests

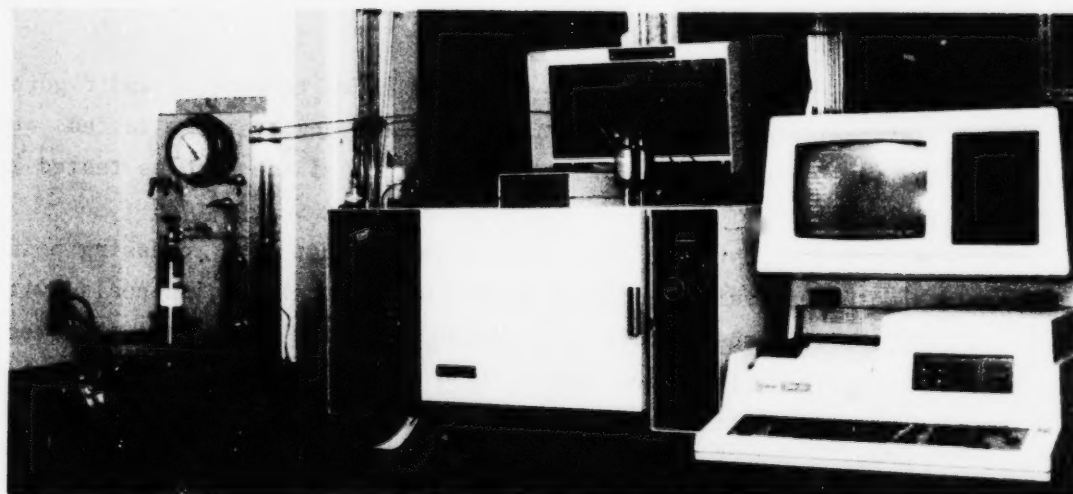


Figure 6. The head gas analysis system using gas chromatograph

TABLE: 1

CROSSING POINT TEMPERATURE AND LIABILITY INDEX
FOR SEVERAL WESTERN CANADIAN COALS

SAMPLE NUMBER	SAMPLE DESCRIPTION	CROSSING POINT TEMPERATURE (°C)	HEATING RATE (°C/MIN)	LIABILITY INDEX
A	SASKATCHEWAN LIGNITE	186	1.50	8.61
B	ALBERTA FOOTHILLS HIGH VOLATILE BITUMINOUS	162.5	1.36	8.37
C	ALBERTA FOOTHILLS HIGH VOLATILE BITUMINOUS	164	1.33	8.11
D	ALBERTA PLAINS SUB BITUMINOUS	173	1.24	7.17
E	ALBERTA PLAINS SUB BITUMINOUS	180	1.28	7.11
F	ALBERTA FOOTHILLS HIGH VOLATILE BITUMINOUS	164	1.09	6.65
G	ALBERTA FOOTHILLS HIGH VOLATILE BITUMINOUS	155	1.35	8.71
H	ALBERTA MOUNTAINS LOW VOLATILE BITUMINOUS	180	0.70	3.89
J	ALBERTA MOUNTAINS LOW VOLATILE BITUMINOUS	193	1.10	5.70

TABLE: 2
PROXIMATE ANALYSIS OF COAL SAMPLES

SAMPLE NUMBER	DESCRIPTION	MOISTURE (%)	V.M. (%)	ASH (%)	F.C. (%)	CONDITION
A	SASKATCHEWAN LIGNITE	33.7	26.93 40.62	6.26 9.44	33.11 49.94	AIR DRY DRY BASIS
B	ALBERTA FOOTHILLS HIGH VOLATILE	11.9	36.58 41.52	8.10 9.19	43.42 49.29	AIR DRY DRY BASIS
C	ALBERTA FOOTHILLS HIGH VOLATILE BITUMINOUS	12.3	36.29 41.38	7.31 8.33	44.10 50.29	AIR DRY DRY BASIS
D	ALBERTA PLAINS SUB BITUMINOUS	19.9	30.86 38.53	7.05 8.80	42.19 52.67	AIR DRY DRY BASIS
E	ALBERTA PLAINS SUB BITUMINOUS	19.6	28.90 35.95	9.02 11.22	42.48 52.83	AIR DRY DRY BASIS
F	ALBERTA FOOTHILLS HIGH VOLATILE BITUMINOUS	8.1	33.66 36.63	9.32 10.14	48.92 53.23	AIR DRY DRY BASIS
G	ALBERTA FOOTHILLS HIGH VOLATILE BITUMINOUS	7.8	34.90 37.86	7.85 8.51	49.45 53.63	AIR DRY DRY BASIS
H	ALBERTA MOUNTAINS LOW VOLATILE BITUMINOUS	1.7	15.21 15.47	7.86 8.00	75.23 76.53	AIR DRY DRY BASIS
J	ALBERTA MOUNTAINS	3.0	18.13 18.69	15.64 16.12	63.23 65.19	AIR DRY DRY BASIS

TABLE: 3
ULTIMATE AND PETROGRAPHIC ANALYSIS

SAMPLE NUMBER	DESCRIPTION	PETROGRAPHIC ANALYSIS EXINITE (%)	ULTIMATE ANALYSIS DRY ASH FREE BASIS (%)		
			CARBON	OXYGEN	SULFUR
A	SASKATCHEWAN LIGNITE	2.3	70.50	24.01	0.83
B	ALBERTA FOOTHILLS HIGH VOLATILE BITUMINOUS	5.0	79.48	11.90	0.43
C	ALBERTA FOOTHILLS HIGH VOLATILE BITUMINOUS	6.6	82.76	9.41	0.23
E	ALBERTA PLAINS SUB BITUMINOUS	6.4	75.56	20.13	0.13
F	ALBERTA FOOTHILLS HIGH VOLATILE BITUMINOUS	6.6	78.55	15.27	0.10
G	ALBERTA FOOTHILLS HIGH VOLATILE BITUMINOUS	3.1	75.10	18.61	0.22
J	ALBERTA MOUNTAINS LOW VOLATILE BITUMINOUS	0.3	88.27	5.47	0.62

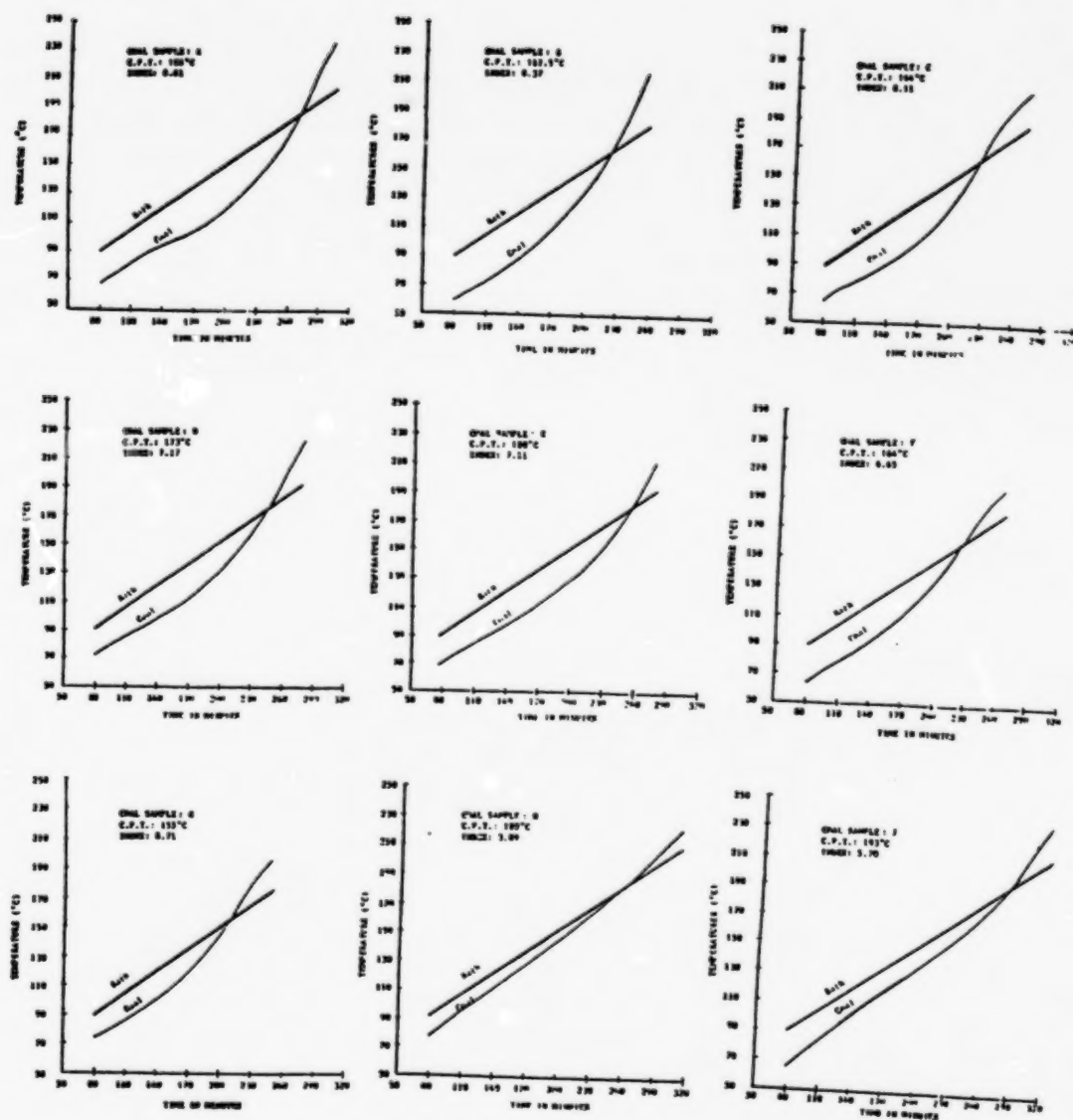


Fig. 7 Crossing point temperature graphs for nine different coals from Western Canada.

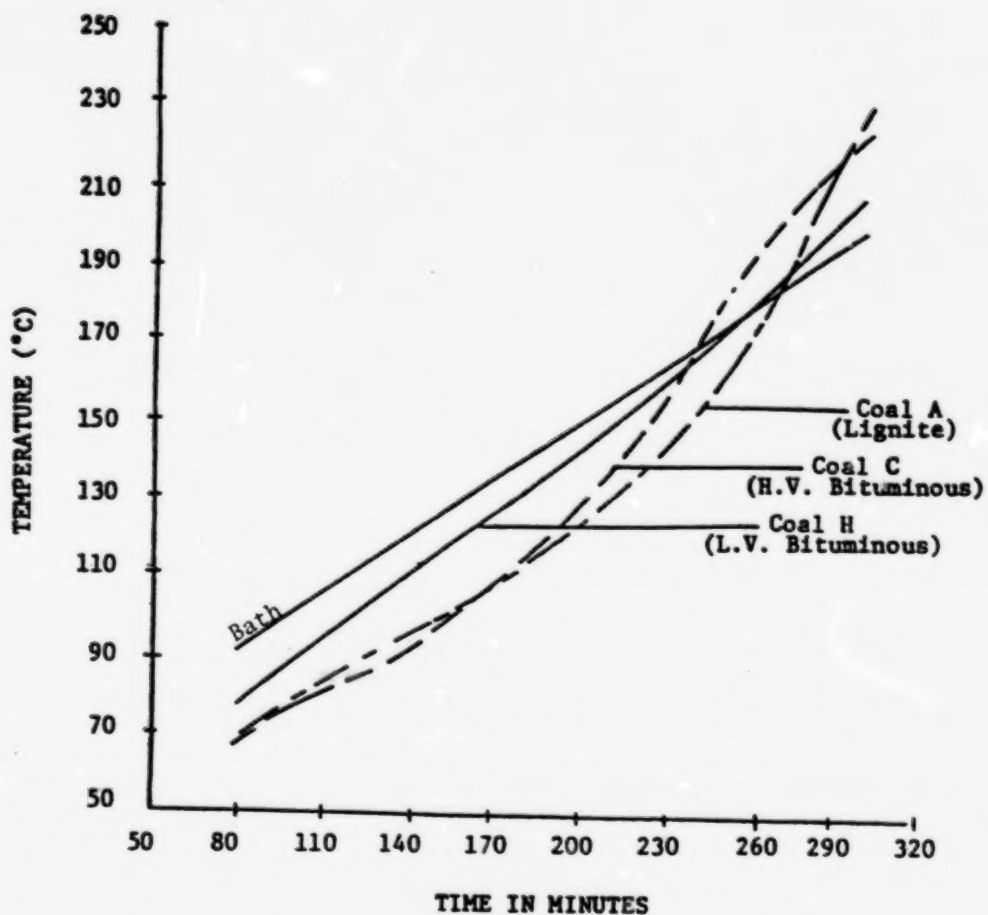


Fig. 8 - Crossing point temperature graphs for three different coals (Metallurgical, High Volatile Bituminous, and Lignite).

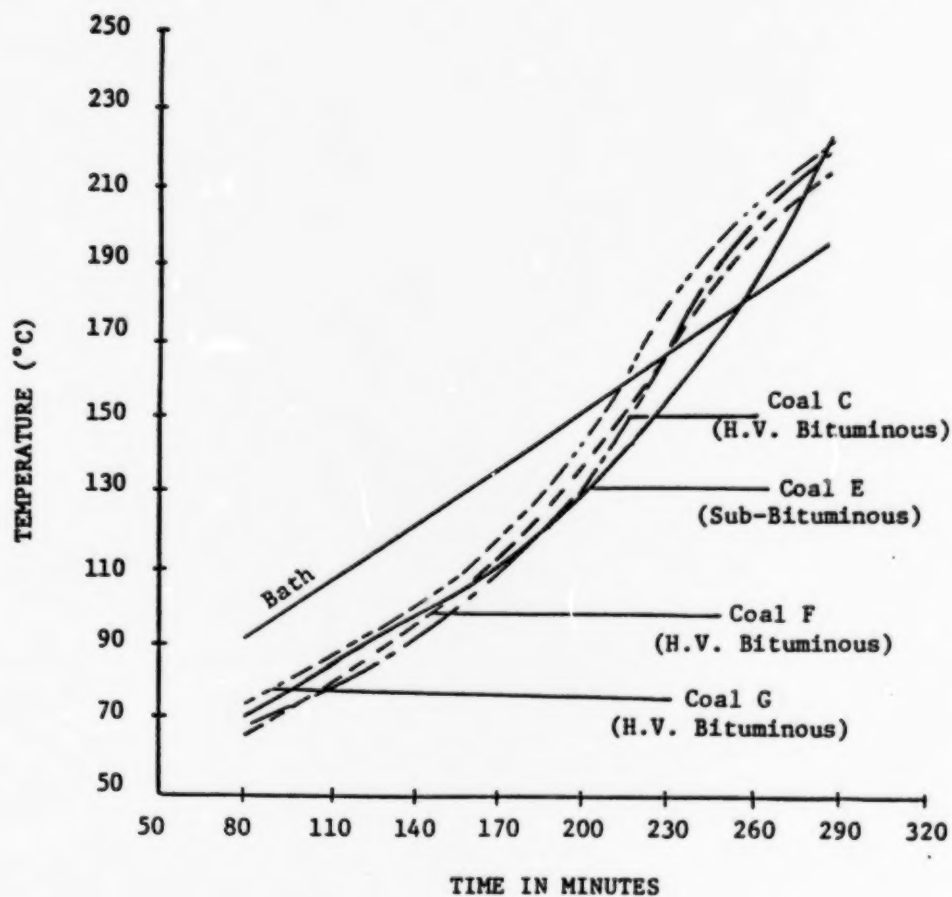


Fig. 9 Crossing point temperature graphs for high volatile bituminous and sub-bituminous coals from Alberta coalfields.

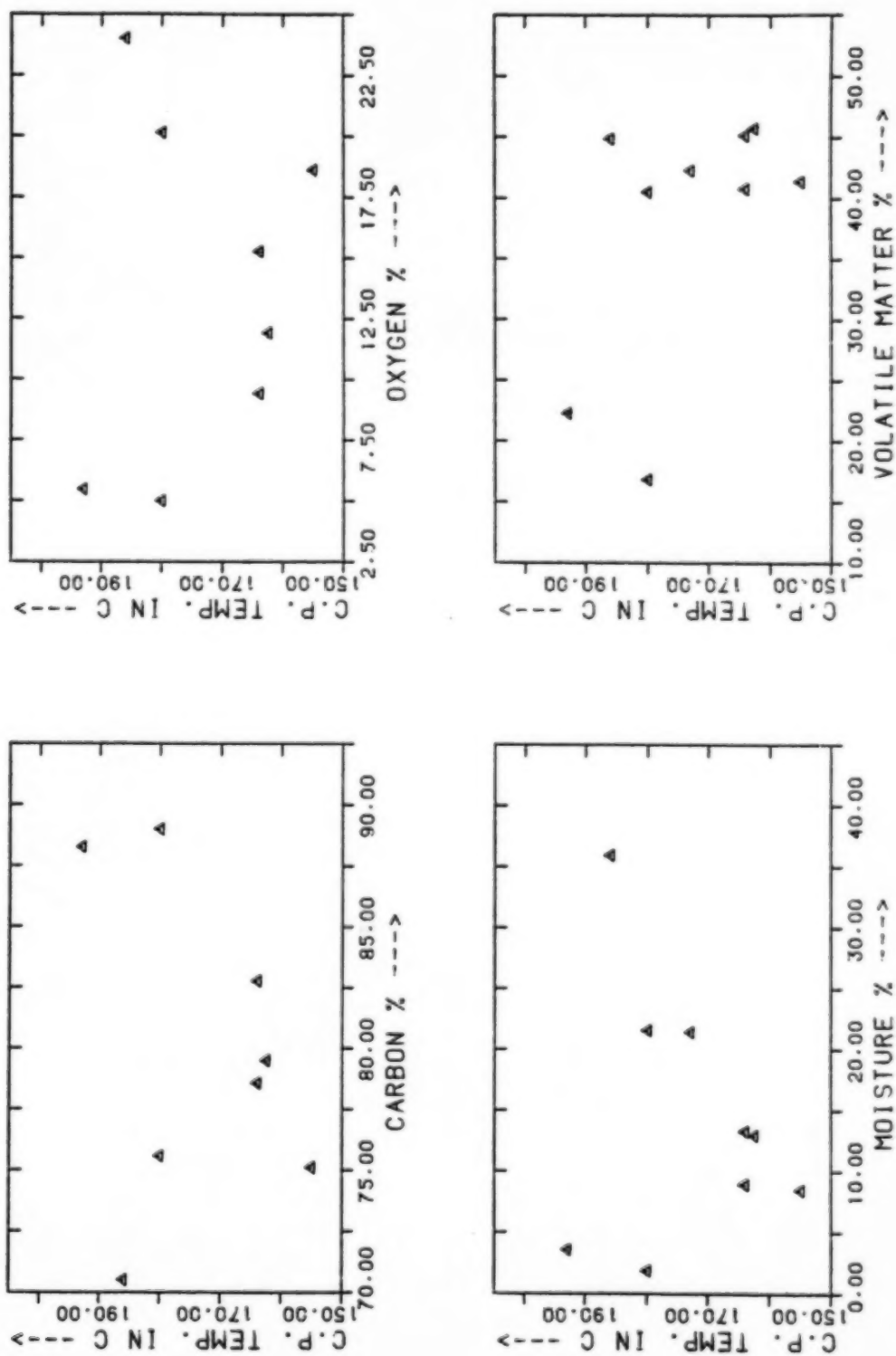


Fig. 10 Crossing point temperature as a function of carbon, oxygen, moisture and volatile matter.

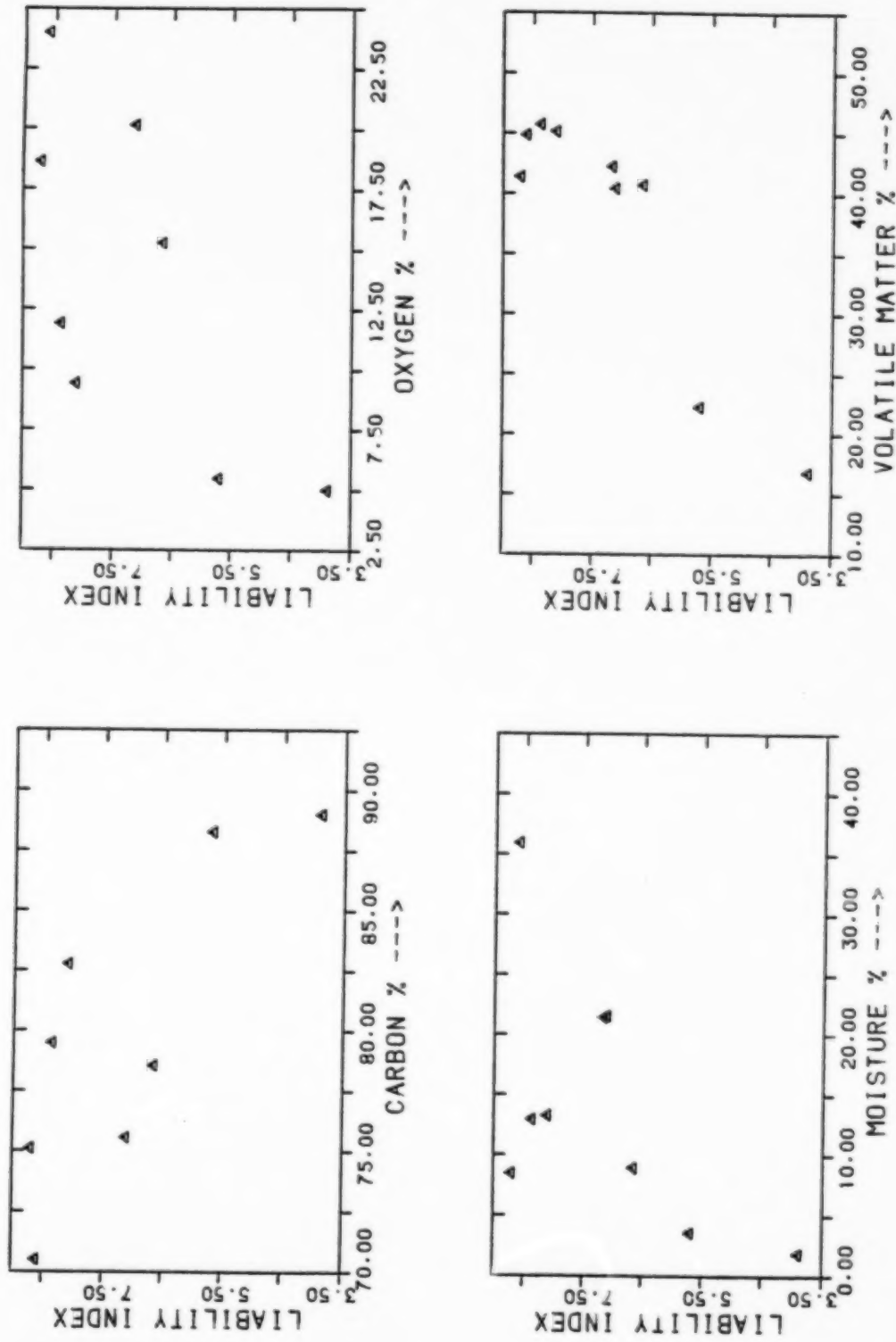


Fig. 11 Liability index as a function of carbon, oxygen, moisture and volatile matter.

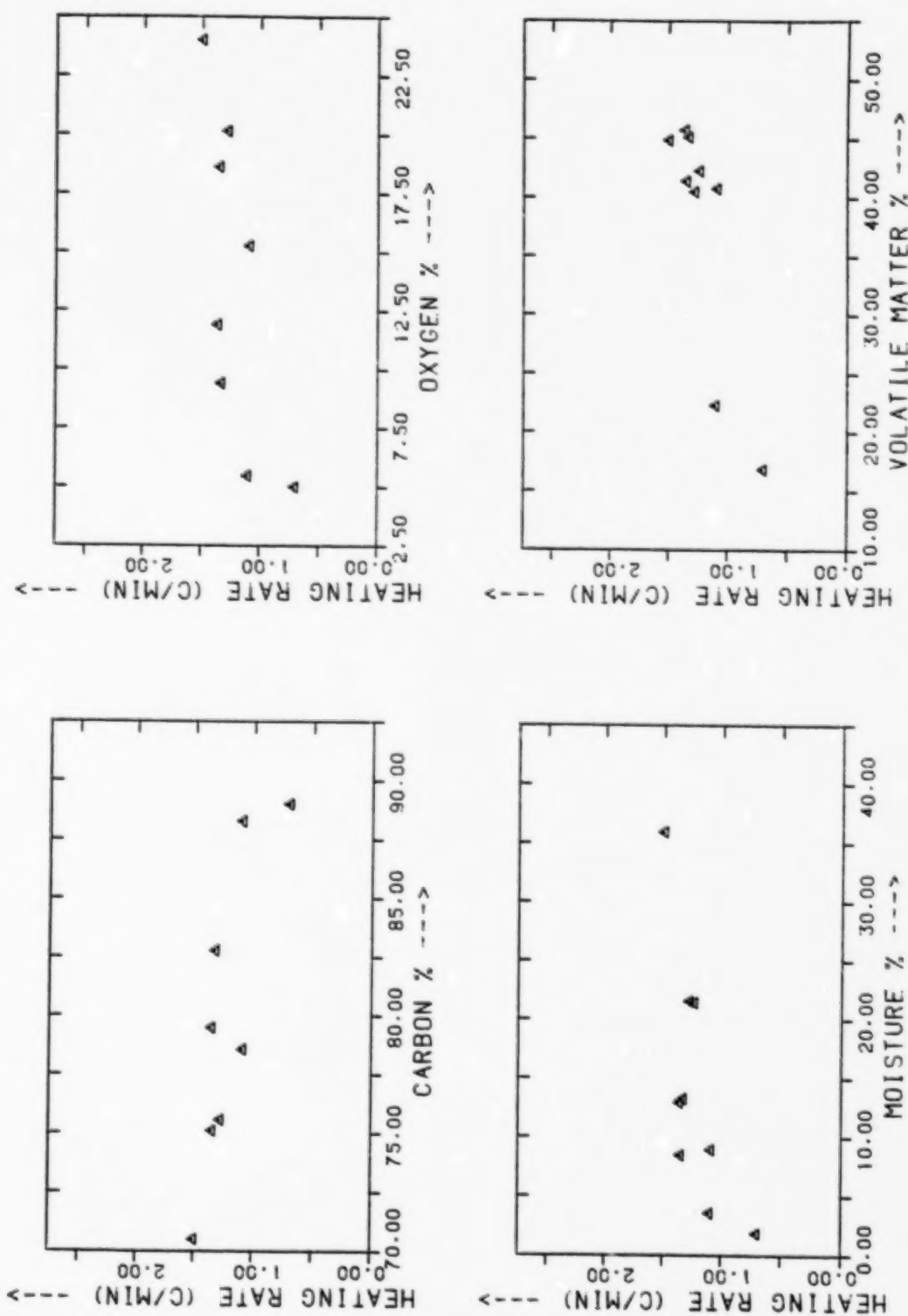


Fig. 12 Heating rate at crossing point as a function of carbon, oxygen, moisture and volatile matter.

temperature increases with the carbon content of coals. It may be inferred that the crossing point temperature is likely to increase with the increase in coal rank.

Figure 10 also shows the variations in the crossing point temperature with oxygen, moisture and volatile matter. As expected the values were found to decrease with the increase in volatile matter and oxygen content. However in the case of high moisture coals the crossing point temperature showed some anomaly as evident from Figure 10. For coals with 12% or more moisture content, the crossing point instead of decreasing appeared to increase to some extent as shown in Figure 10. It seems that the cooling effect caused due to the evaporation of large amount of moisture may be responsible for this apparent anomaly, thus increasing the crossing point temperature inspite of decrease in coal rank. However, it is obvious from these graphs (Figures 7 - 9) that once the moisture is removed the rate of rise of coal bed temperature is significantly increased confirming that high moisture coals will become extremely vulnerable to spontaneous combustion once they are partially dried.

Because of this apparent anomaly the use of crossing point temperature alone as a criterion for determining spontaneous combustion susceptibility of coal may lead to erroneous conclusions. To alleviate this problem the concept of liability index was introduced which is based on the ratio of the rate of heating of coal bed at crossing point and the crossing point temperature [5]. This index is considered to be more appropriate for classifying coals with respect to their susceptibility to spontaneous combustion. Table 1 shows the liability index values for different coals tested. Figure 11 also shows the variation of liability index as a function of carbon, oxygen, moisture and volatile matter. Figure 12 shows the variation in the heating rate at "crossing point" with carbon, oxygen, moisture and volatile matter content of coal. It is believed that heating rate could be a useful guide in coal categorization.

Oxygen absorption values given in Table 5 also indicated quite a large variation with rank. With samples of lignite the value obtained ranged from 200ml/100gm to 350ml/100gm of coal. With high volatile bituminous and subbituminous coals oxygen absorption values were between 100 - 200 ml/100gm. For low volatile coals oxygen absorption was almost negligible and of the order of 50ml or less. Table 4 also shows the amount

TABLE: 4

ABSORPTION OF OXYGEN AND FORMATION OF CARBON MONOXIDE
FOR SEVERAL WESTERN CANADIAN COALS (AT 20°C).

SAMPLE NO.	SAMPLE DESCRIPTION	OXYGEN ABSORPTION (C.C)		CO FORMATION (PPM)	
		48Hours	96Hours	48Hours	96Hours
A	SASKATCHEWAN LIGNITE	111.6	223.2	105.2	210.5
C	ALBERTA FOOTHILLS HIGH VOLATILE BITUMINOUS	171.2	247.7	1027.0	1756.7
D	ALBERTA PLAINS SUB BITUMINOUS	71.6	143.2	113.1	226.2
E	ALBERTA PLAINS SUB BITUMINOUS	48.3	96.6	32.9	65.8
F	ALBERTA FOOTHILLS HIGH VOLATILE BITUMINOUS	92.6	141.4	668.5	1063.9
G	ALBERTA FOOTHILLS HIGH VOLATILE BITUMINOUS	94.5	139.3	613.0	971.7
J	ALBERTA MOUNTAINS LOW VOLATILE BITUMINOUS	1.4	9.1	0.0	42.9

of carbon monoxide produced during the same period. It is obvious from these results that the production of carbon monoxide also depends on the nature of coal. Coals which are highly prone to spontaneous combustion produced relatively high amounts of carbon monoxide. Based on these results it can be concluded that categorization based on oxygen absorption and carbon monoxide production is a possibility for Western Canadian coals.

During the first phase of experiments, it was often necessary to keep the coal samples bottled in an inert atmosphere for several months because of the lack of adequate test facilities at the Calgary laboratory. It was observed that the tests carried out on freshly mined coal samples in general, showed a relatively high oxygen absorption values compared to coals preserved in argon or nitrogen over an extended period. It is now planned to study this phenomenon in greater details.

During the oxygen absorption tests, the nature of pressure drop in the test vessels were also studied. The results are shown in Figure 13 and 14. It can be seen that coals such as C & D considered as highly susceptible to spontaneous combustion also showed a large pressure drop during the initial stage. It is therefore believed that the nature and extent of pressure drop may also be used during categorization of coals for spontaneous combustion liability.

The exinite content of all the high volatile bituminous or sub-bituminous coal samples were found to be over 3% thereby confirming that there is a direct relationship between exinite content and susceptibility to spontaneous heating. Low volatile metallurgical coals are also low in exinite content and both crossing point temperature and oxygen absorption tests showed values which indicate that they are not highly susceptible to spontaneous heating.

CONCLUSIONS

The determination of crossing point temperature appear to be a suitable method for classifying Canadian coals with respect to their susceptibility to spontaneous combustion. However, with high moisture coals, crossing point temperature alone may sometimes lead to erroneous results. The liability index based on the ratio of the rate of temperature rise and crossing point temperature is considered to be a better guide and is recommended for such categorization.

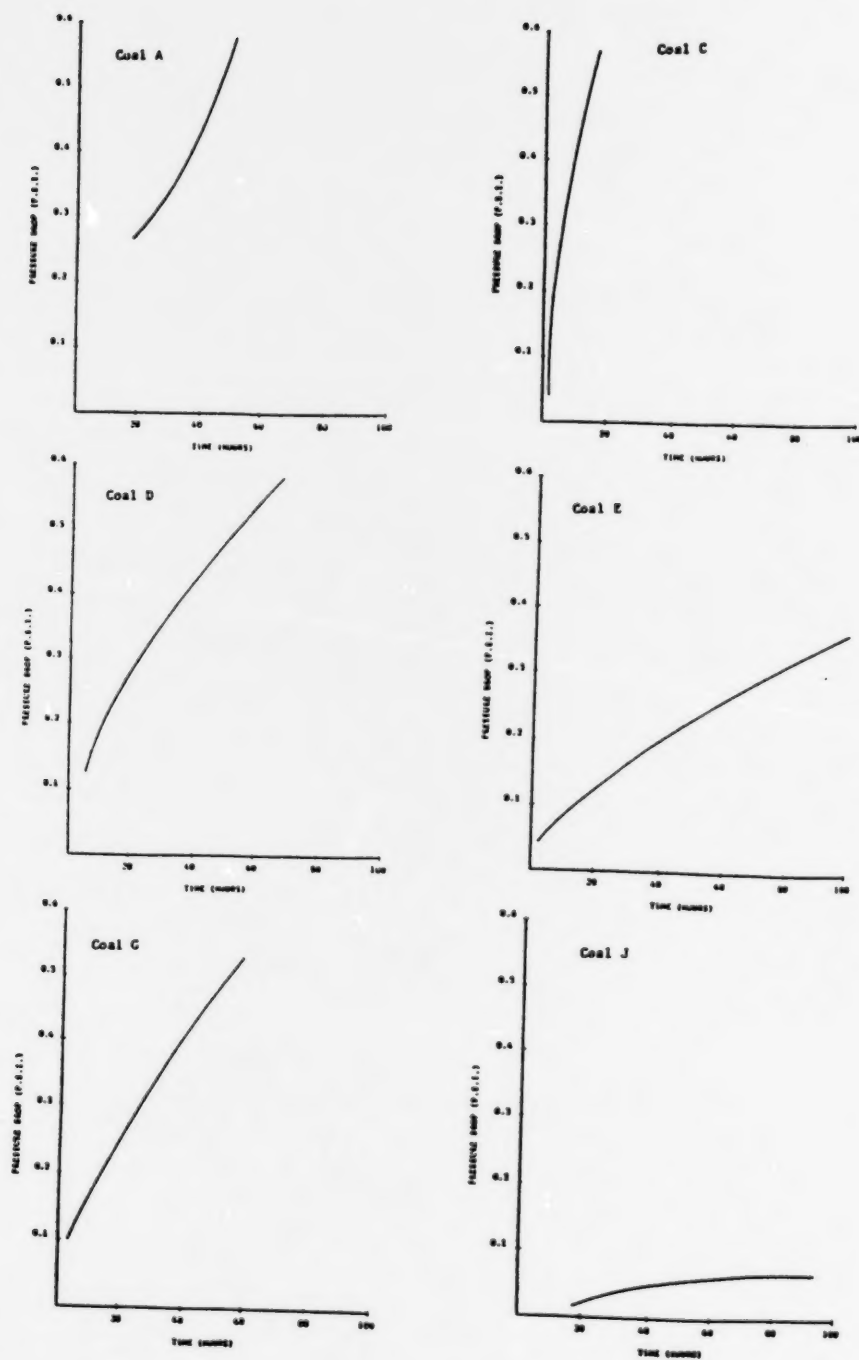


Fig. 13 Pressure drop graphs for several western Canadian Coals of different rank.

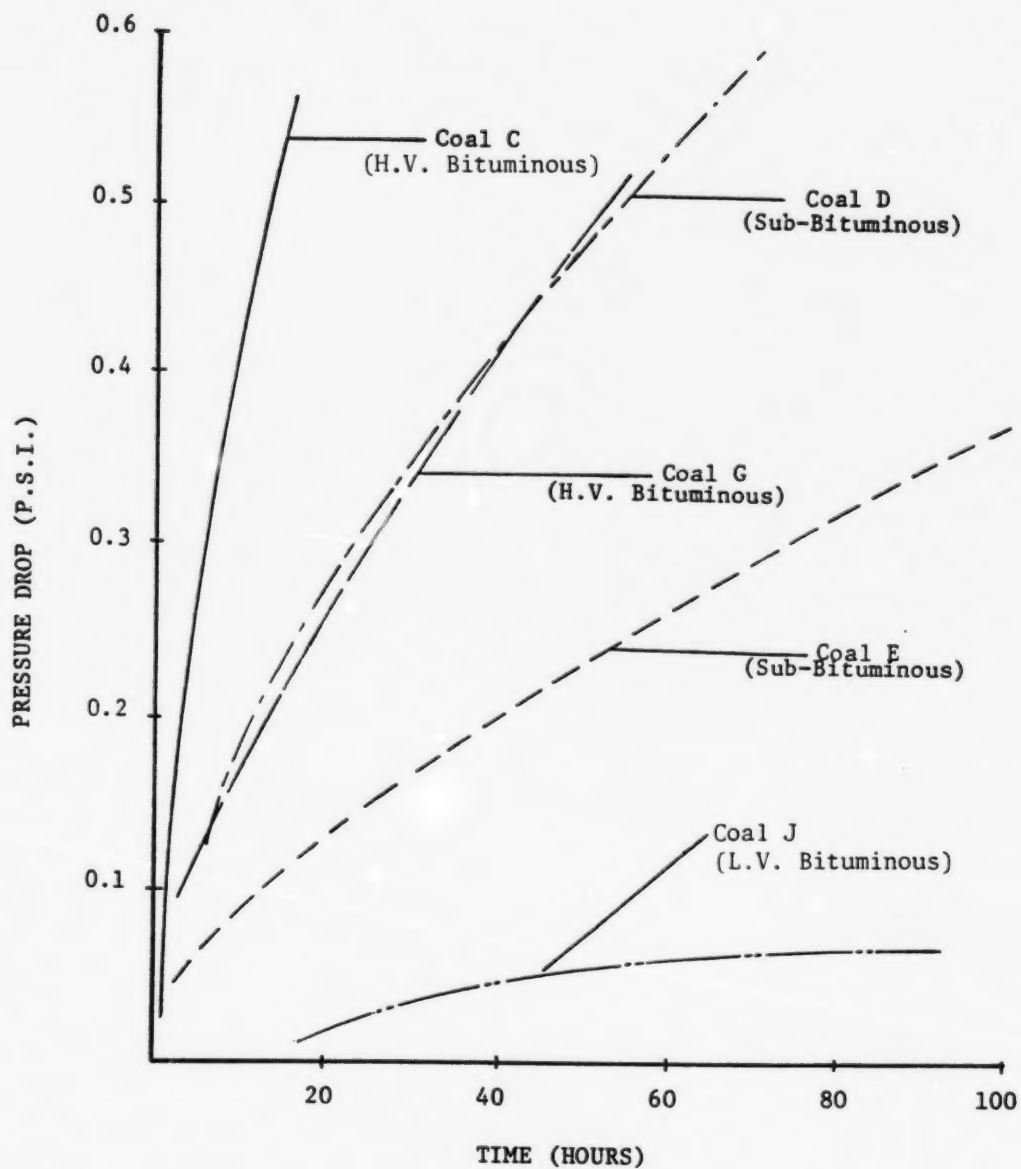


Fig. 14 Graphs showing nature of pressure drop with time for coals of different ranks.

The test method based on the amount of oxygen absorbed and the carbon monoxide produced (under static isothermal conditions) is a very simple and a practical method for finding out spontaneous combustion liability of different coals and should prove very popular with coal mine operators as the test requires minimum instrumentation and operating personnel. The nature of pressure drop may also prove useful for a quick indication of coal liability to spontaneous combustion.

All the laboratory tests have shown that in general higher rank coals are less susceptible to spontaneous combustion than low rank coals. Most of the high volatile bituminous coals from Alberta showed that they are quite prone to spontaneous combustion. It was also observed that with high moisture coals the liability to spontaneous combustion was considerably increased after the coal samples were partially dried suggesting that the various proposed upgrading processes for low rank coal may contribute significantly to spontaneous combustion susceptibility as a result of moisture reduction.

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